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A TEN KILOMETER TRANSMISSION SYSTEM

FIBER OPTICS VERSUS KU-BAND

BY

JOHN A. HALLMARK, JR., P.E.
B.S.E.E. AUBURN UNIVERSITY 1957

RESEARCH REPORT

Submitted in partial fulfillment of the requirements
for the degrees of Master of Science in Engineering
in the Graduate Studies Program of the College of Engineering
at the University of Central Florida; Orlando, Florida

Winter Quarter
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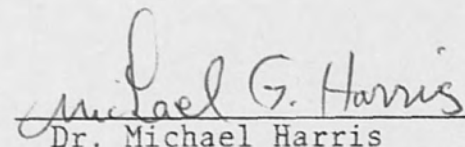
A TEN KILOMETER TRANSMISSION SYSTEM
FIBER OPTICS VERSUS KU-BAND

JOHN A. HALLMARK, JR.

ABSTRACT

This research paper discusses the design, evaluation and selection of a transmission system to be used in checking out the Spacelab high rate data system. The transmission systems evaluated are discussed, as well as the criteria utilized in selecting the final system. The installation of a fiber optics cable and the testing of this cable are discussed. The determination of the optimum location of the high rate data bit synchronizer and the Viterbi decoder is presented. Utilization of this data to justify the installation of a shorter fiber optics system inside the O&C Building is presented.

Approved by:


Dr. Michael Harris

Director of Research Paper

TABLE OF CONTENTS

Chapter

I.	INTRODUCTION	1
II.	SPACELAB HIGH RATE DATA SYSTEM	2
III.	TRANSMISSION SYSTEMS	5
	KU-Band System	6
	Fiber Optics System.	10
✓ IV.	FIBER OPTIC CABLE INSTALLATION	14
✓ V.	FIBER OPTIC CABLE TESTING.	19
✓ VI.	CONCLUSIONS.	24

APPENDICES

I	RF ATTENUATION	26
II	RECEIVER INPUT REQUIREMENTS.	29
III	FADING	32
IV	EQUIPMENT LOCATION	35

GLOSSARY.	43
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BIBLIOGRAPHY	45
------------------------	----

LIST OF FIGURES

Figure

1.	Transmission System Path	3
2.	KU-Band Block Diagram	7
3.	KU-Band Link Power Level	9
4.	3 Fiber Optic Lines with Signal Conditioning-Option 5 .	12
5.	Fiber Optic Cable	16
6.	Fiber Optic Test Cable Route	18
7.	Link Configuration Diagram	22
8.	KU-Band RF Signal Path	27
9.	Fiber Optics Equipment Location Option 1	36
10.	Fiber Optics Equipment Location Option 2	37
11.	Fiber Optics Equipment Location Option 3	39
12.	Fiber Optics Equipment Location Option 4	40
13.	Fiber Optics Equipment Location Option 5	42

CHAPTER I

INTRODUCTION

The object of this research paper is to determine the most practical way of transmitting Spacelab high rate data to the Operation and Checkout building (O&C) for evaluation while the Spacelab is at the Orbiter Processing Facility (OPF) or at the pad. The Communications and Tracking (C&T) Station located in the OPF will have access to the KU-Band RF data originating in the Spacelab. This station can accept the KU-Band RF from either the orbiter in the OPF bay or from a retransmit antenna at the launch pad. The data in the KU-Band RF link consist of four possible Spacelab data streams: wideband data up to 50 MBPS and medium band data up to 2 MBPS, 4 MBPS and 4.5 MHz. These data streams are available at the C&T KU-Band downlink rack; however they must be transmitted to the O&C building for demultiplexing and evaluation. This research paper details the processes followed in determining the best transmission system to be implemented for the 0 to 50 MBPS data. Chapter II covers the spacelab high rate data system. Chapter III discusses the two transmission systems to be evaluated. Chapter IV describes the fiber optic cable installation. Chapter V describes the testing performed on the fiber optic cable before and after installation. Chapter VI presents a summary of the research done and suggests additional applications and research.

CHAPTER II

SPACELAB HIGH RATE DATA SYSTEM

Spacelab planning calls for the installation of a high rate multiplexer (HRM) as part of the Spacelab Command and Data Management System (CDMS). The purpose of the HRM is to combine data from multiple sources into a single (up to 50 MBPS) digital data stream for transmission, via the orbiter KU-Band system and the Transmit Data Relay Satellite System (TDRSS), to a ground station for data evaluation. The ground station data will then be demultiplexed, that is divided into separate data streams, for evaluation by individual experimenters.

Present planning for Spacelab checkout at KSC requires that the high rate data system be tested while the Spacelab is in the O&C building and at the OPF. Budgetary considerations have required that only one set of Ground Support Equipment (GSE) will be available. Prior evaluations have shown that the optimum location for this GSE is near the Spacelab workstands in the O&C building. This location now requires that a transmission system be installed to get the high rate data from the OPF and/or the pad to the O&C building (See Figure 1) for evaluation. Of the transmission systems considered, two appear to be feasible. These two transmitting systems are the KU-Band RF System and the Fiber Optics System.

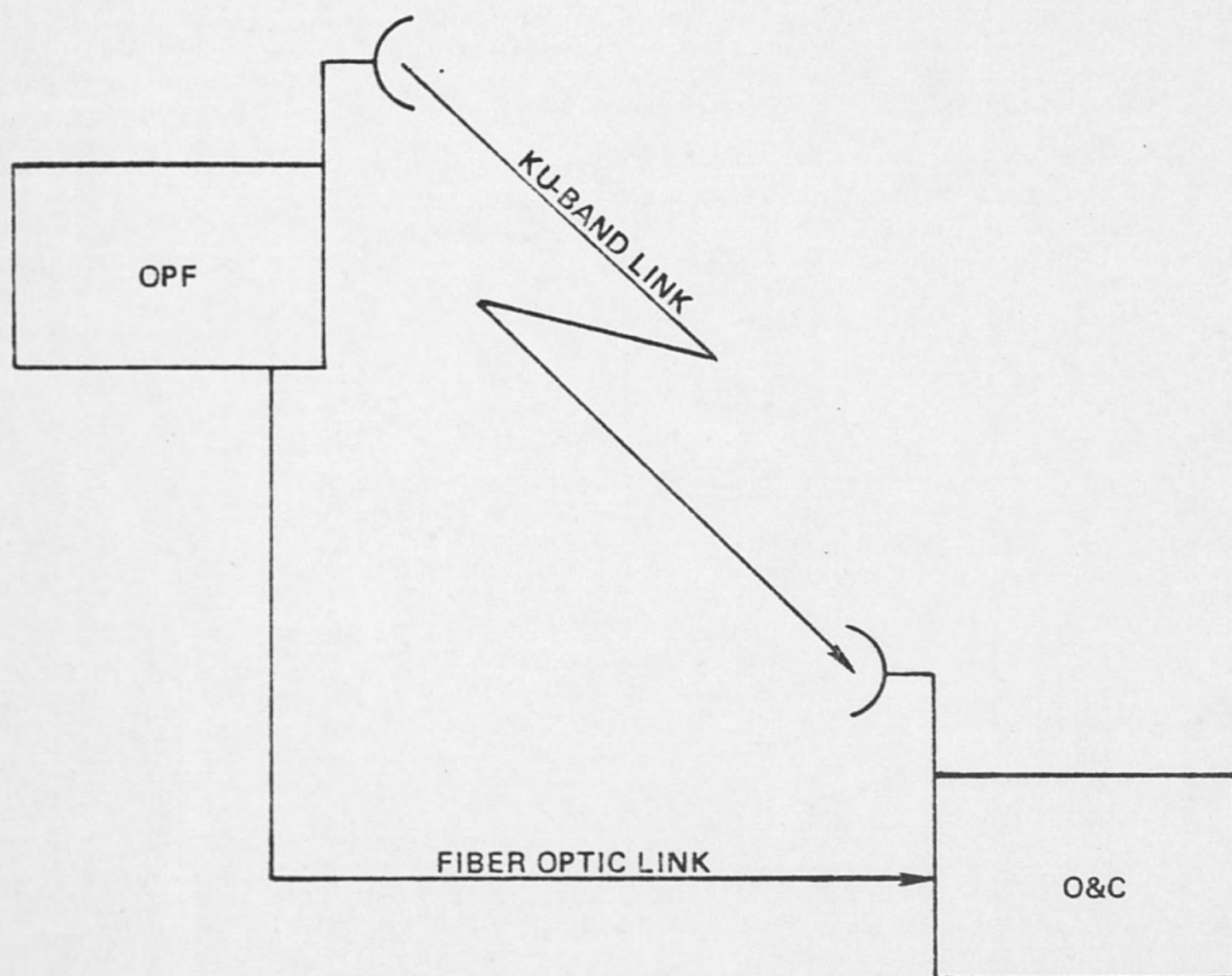


Figure 1. Transmission system path

The following chapters describe these two systems and a portion of the evaluation performed prior to choosing one of the systems.

CHAPTER III

TRANSMISSION SYSTEMS

Three Transmission concepts have been studied as possible transmission systems for the 50 MBPS Spacelab data. The three systems considered were a microwave system, a KU-band system and a fiber optics system. The microwave system was rejected because of the high equipment cost, caused mainly by the required bandwidth. The KU-band system appeared to be feasible, since the Viterbi decoder could be located in the O&C Building and utilized not only for Spacelab checkout, but also for Orbiter checkout. This allowed a savings of \$250,000 for one Viterbi decoder. This method of operation required basically an antenna and waveguide system at the OPF and the O&C building, an RF receiver, three demodulators, two low-pass filters, and the required cabling. Estimates for the installation of this system were approximately \$535,000.

2 The fiber optic system has been under consideration by KSC since 1977. Many problems connected with fiber optic usage have either been solved, or are in the process of being resolved. At the time of this writing, the bundle-vs-single fiber struggle appears to be over, with single fibers becoming more popular. With the help of FOCIS (Fiber Optic Communication and Information Society), cables and connectors are being standardized. This method of opera-

tion requires basically three fiber optic transmitters, a three fiber cable, three repeaters, a clock generator, three fiber optic receivers, the necessary mounting racks and the required cabling. Estimates for the installation of this system were approximately \$473,000.

KU-Band System

The RF portion of the KU-Band transmission system includes the equipment between the Orbiter transmitter in the Orbiter Processing Facility (OPF) and the receiver in the O&C building (See Figure 2). RF is transmitted from the Orbiter GSE coupler through waveguides to the transmitting antenna on the roof of the OPF. The RF is then transmitted to the receiving antenna on the roof of the O&C building where it is transmitted again through waveguides to the KU-Band receiver. Gain margin calculations have confirmed that the Orbiter KU-Band transmitter is capable of driving this system without the need for in-line driving amplifiers. Appendices I, II and III present the transmission system analysis considering RF Signal Attenuation (Appendix I), Required Receiver Input Level (Appendix 2) and Fading (Appendix III). Analysis of the RF attenuation characteristics (Appendix I) found the signal level to the receiver to be -65.5 dbm, which is 7.2 dbm more signal than the required receiver level of -72.7 dbm (Appendix II) and over five times the needed signal strength. Analysis of the receiver input requirements (Appendix II) showed that the receiver needs a minimum of -72.7 dbm to achieve a required Bit Error Rate (BER) of less than 10^{-6} . Fading

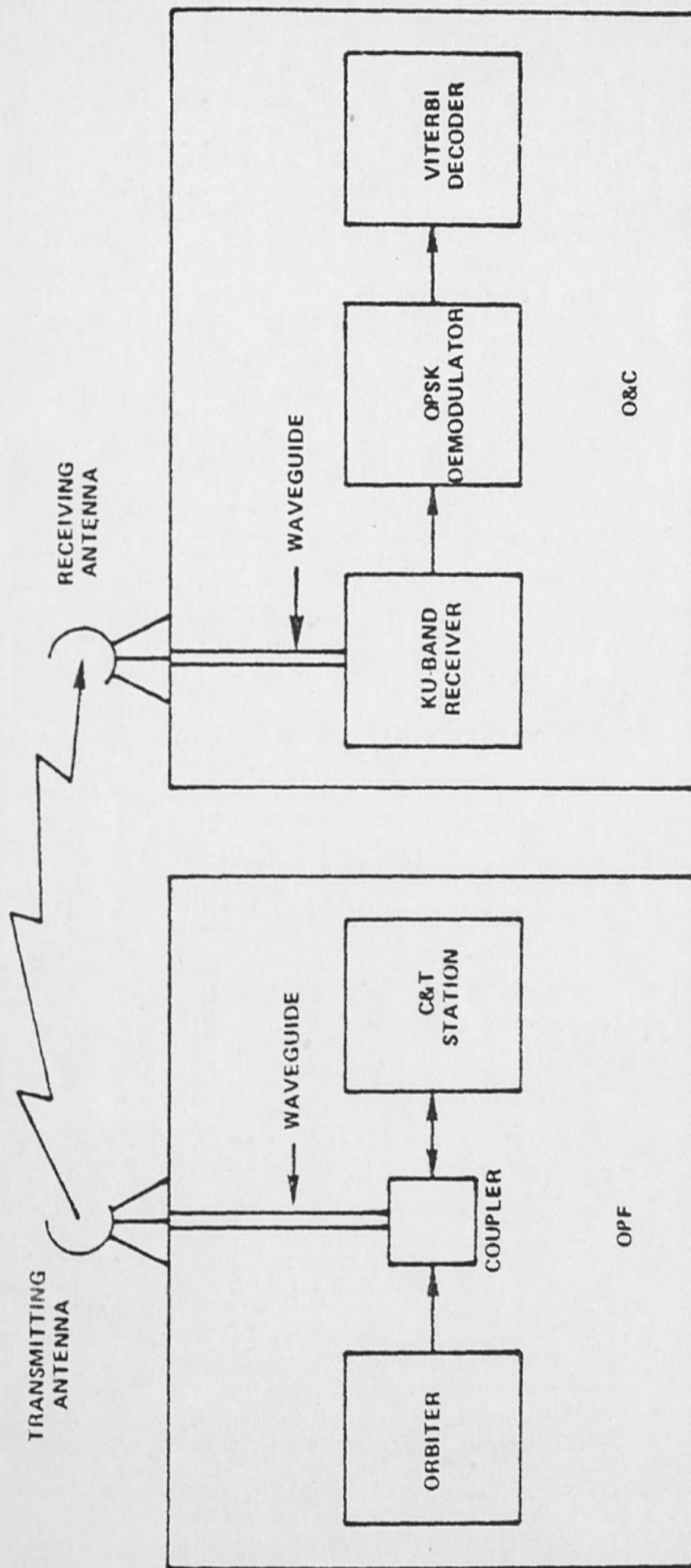


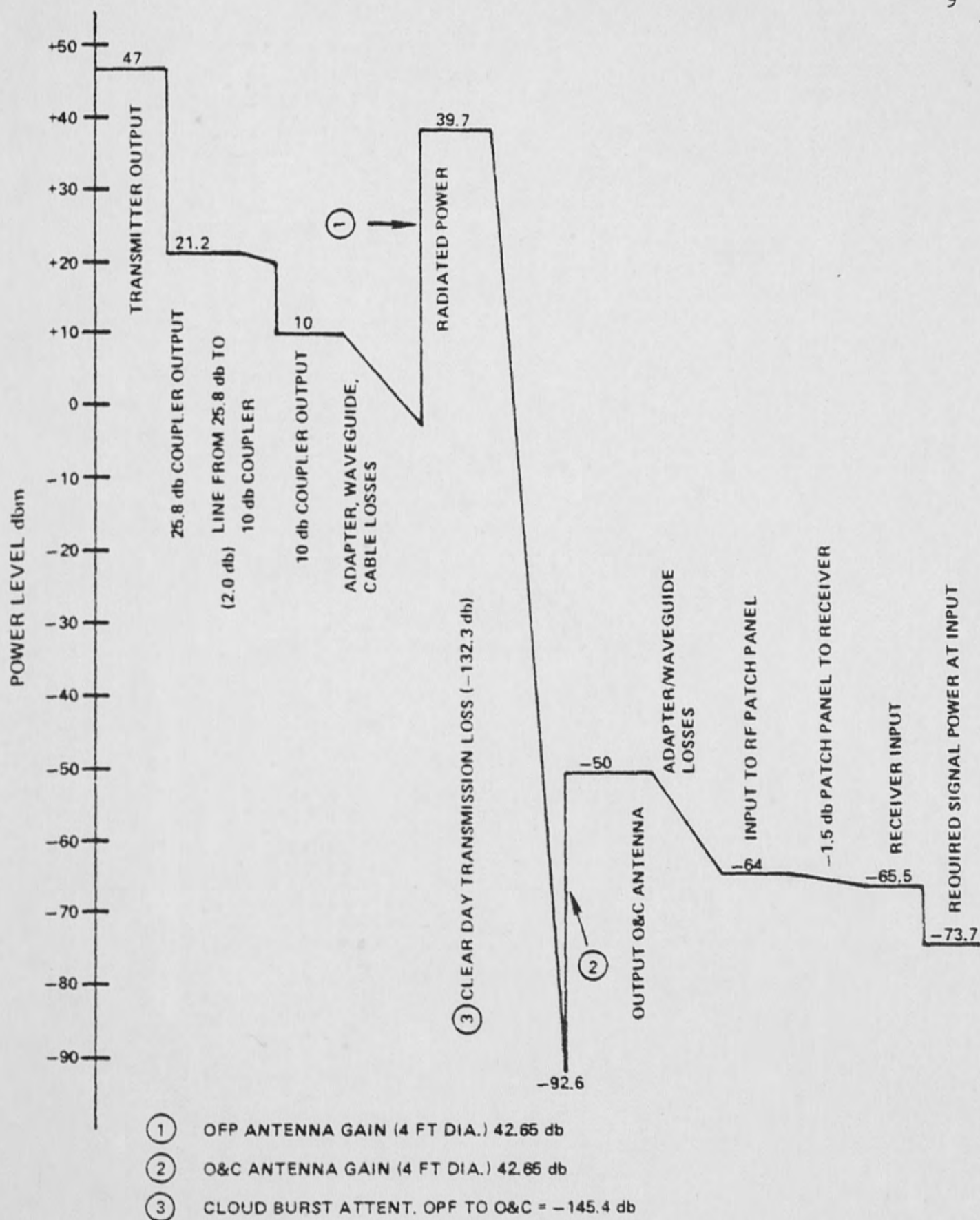
Figure 2. Ku-band block diagram

analysis (Appendix III) indicated no problems with signal reflection. Weather conditions were shown to pose no problem unless a heavy cloudburst encompassed the entire area. This condition would decrease the required signal strength to a level below the receiver signal input level.

An RF station capable of receiving, demodulating and decoding the KU-Band RF signal would be installed in the O&C building. The means to accomplish this task is to utilize a KU-Band receiver, a quadrature phase shift key (QPSK) demodulator, and a Viterbi decoder to perform these functions. The capability and hardware exist to perform these functions with respect to the Spacelab data.

Analysis of the RF station equipment indicates a minimum signal level of -74 dbm for a bit error rate of less than 10^{-6} . Calculations in Appendix II indicate a minimum required signal level of -7.27 dbm. From the link power level shown in Figure 3, the signal level anticipated at the receiver is -65.5 dbm. These figures give a minimum of 7 db margin for proper reception of the RF signal.

The 50 MPBS data requires a close correlation with its clock (HRDM maximum data/clock phasing is ± 7.0 ns). To maintain this data/ clock phasing and to maintain the required pulse rise time, a short fiber optic link from the output of the Viterbi decoder to each test stand is to be installed. This method has been demonstrated at KSC and will not entail the uncertainty of a coax line providing proper step response. These optical links will have monitor detectors at the sending transmitters with the data displayed on an oscilloscope.



LINK POWER LEVEL DIAGRAM

Figure 3. Ku-band link power level

Fiber Optic System

The fiber optic system was first considered for the checkout of the HRDS at KSC in 1977. However, since it was a state-of-the-art system, it was not a strong contender. By 1978 fiber optic technology had progressed, not only to a reliable level, but was becoming economically competitive. A turn-key system, consisting of a bit synchronizer, three fiber optic transmitters, a three fiber cable, three repeaters, a clock generator, three fiber optic receivers, the necessary mounting racks, and the required connecting cabling, was estimated to cost \$473,000. Since the system was cost-competitive, five options were studied (see Appendix IV). These options utilized approximately the same equipment; however, the options studied the characteristics with the equipment placed at various locations. The matrix in Table 1 lists the options and parameters investigated. Eventually Option 5 (Figure 4) was chosen. This option locates a soft decision bit synchronizer and the Viterbi decoder in the OPF in close proximity to the KU-Band receiver. The manufacturer has designed the two devices to operate together so no interference problem should exist if they remain together. The decoded data and clock from the output of the Viterbi decoder are in phase, and since both outputs are low noise-low distortion digital signals they can easily be terminated in a fiber optic driver circuit. In the OPF, the 100 MSPS data from the KU-Band demodulator feeds directly into the bit synchronizer and on to the Viterbi decoder, both of which are located in the high data rate rack. The two outputs of the Viterbi decoder are a 50 MBPS data

TABLE 1

OPTIONS	1	2	3	4	5
BIT SYNC LOCK INDICATION	O&C	O&C	O&C	O&C	O&C
DATA AND CLOCK PHASING	GOOD	GOOD	GOOD	GOOD	GOOD
DATA LINK CHECKOUT	FAIR	FAIR	FAIR	GOOD	GOOD
DATA QUALITY	QUESTION- ABLE	ACCEPT- ABLE	ACCEPT- ABLE	GOOD	GOOD
EASE OF OPERATION	GOOD	FAIR	FAIR	GOOD	GOOD
MAINTENANCE	GOOD	POOR	GOOD	FAIR	GOOD
MAX BIT RATE TRANSMITTED (NRZ)	100 MSPS	100 MSPS	100 MSPS	50 MSPS PLUS CLK	50 MBPS
NUMBER OF FIBERS	1 DIGITAL	1 ANALOG	1 DIGITAL	2 DIGITAL	1 DIGITAL
OUTPUT AT O&C DRIVE CAPABILITY	GOOD	GOOD	GOOD	GOOD	GOOD

Brief Description

OPTION 1 - Bit Sync and Viterbi at O&C, digital link

OPTION 2 - Bit Sync and Viterbi at O&C, analog link

OPTION 3 - Bit Sync and Viterbi at O&C, second Bit Sync at OPF,
digital linkOPTION 4 - Bit Sync and Viterbi at OPF, two digital links (data and
clock)

OPTION 5 - Bit Sync and Viterbi at OPF, digital link

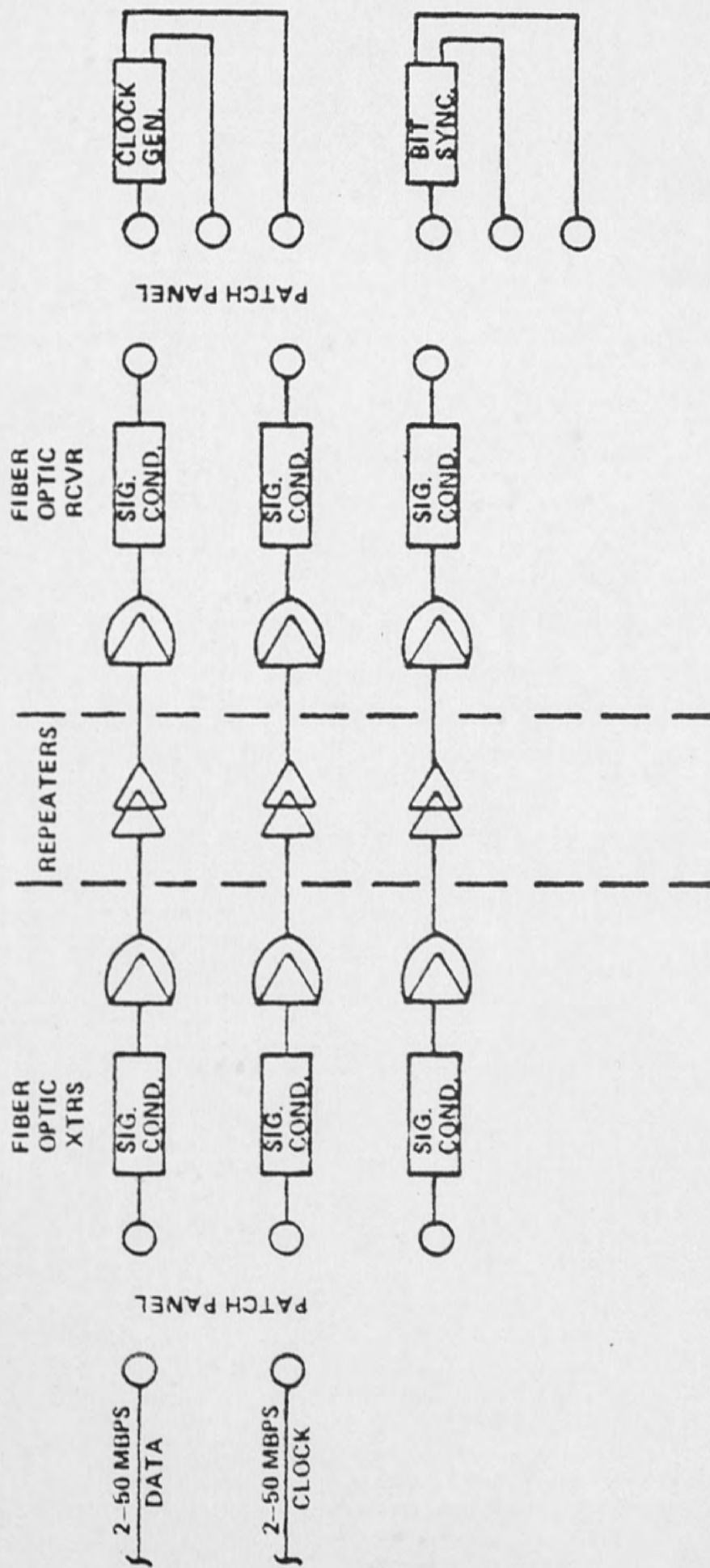


Figure 4. Three fiber optic lines with signal conditioning

signal and an in-phase clock signal. The data and clock are "signal conditioned" and transmitted to the O&C building by a single fiber optic line. In the O&C building, this signal drives a "clock generator" which provides in-phase data and clock signals for distribution. Therefore, any time delay in the line, in the signal conditioning equipment, or in other equipment affects both signals. This option not only supplies a low noise-low distortion interface at the C&T station for the fiber optic transmission link, but also provides a proper phasing relationship between data and clock. The system specification for a fiber optic transmission link is a minimum BER of 10^{-9} or a SNR of 38 db, which include the signal conditioning and associated electronics to drive the lines. The minimum bit transition density for the 50 MBPS data shall be one transition in 64 consecutive bit periods. The signal characteristics required at the OPF are as follows:

Channel 3 - Bit rate 2 MBPS to 50 MBPS, ECL III positive logic, 75 ohm coax line.

Rise and fall times - less than 3 nsec (10%-90%)

The output of the transmission system at the O&C building is to have the following electrical characteristics:

Channel 3 - 2 MBPS to 50 MBPS, 0.5v to 5 v p-p amplitude, 10% to 90%, a rise and fall time of less than 3 nsec, bi-polar 50 ohms. The clock and data phasing at 50% clock fall time shall be centered with the data.

CHAPTER IV

FIBER OPTIC CABLE INSTALLATION

In recent years fiber optic technology has advanced to the point where light communications have become a practical method of conveying information. About five years ago, design engineering decided to look at the feasibility of using fiber optics for bi-directional data communications at the Kennedy Space Center (KSC). Fiber optics appeared to offer an excellent alternative to RF transmission systems because of its inherent high rate data capabilities. It has been demonstrated that there are several advantages to the use of fiber optics. Some of these advantages are:

Complete Electrical Isolation

Wide Signal Bandwidth

Low Attenuation

Wide Operational Temperature Range

Light Weight

Relatively Low Cost

These advantages make fiber optic cables an ideal replacement for some 13,000 miles of paired copper wideband cable in use at KSC.

The data handling capabilities of fiber optics far exceeds the planned communications requirements for a high speed data transmission system. Expansion of the system is possible by increasing the channel capacity through multiplexing or handling different data types. The optimum bandwidth of a signal fiber is approximately

1.3 GHZ. This is more than enough to handle a 50 MBPS data rate and was actually limited by terminal electronics.

To determine the actual usefulness of a fiber optic system, plans were formulated to install a fiber optic cable and conduct a testing program. The cable chosen for the test was manufactured by the General Cable Corporation and contained eleven glass fibers produced by Corning Glass Corporation. The fibers were high grade, low loss glass with a graded index structure. The fibers were five mils in diameter with a core of approximately three mils. The glass was coated with ethylene vinyl acetate (EVA) for strength and protection and is currently in one kilometer lengths. The cable itself was extremely rugged and could withstand a great deal of manipulation without danger of damaging the fibers (See Figure 5).

When the cable was manufactured its attenuation was measured as 6.0 to 6.2 dB/Km with a light source wavelength of 820 nanometers. After installation the attenuation was approximately 10-11 dB/Km with a 632.8 nanometer wavelength.

The actual installation of the cable was much simpler than installing lead or alpath sheathed wideband cable. No extremely sophisticated equipment was needed. A small winch was used to make the two pulls, one from the Flight Crew Training Building (FCTB) to the front of the Headquarters Building and one from there to the Communication and Instrumentation Facility (CIF). The final runs into each building were pulled by hand and were easily manipulated around corners and through walls.

During the cable pulling operation, a Closed Circuit Televi-

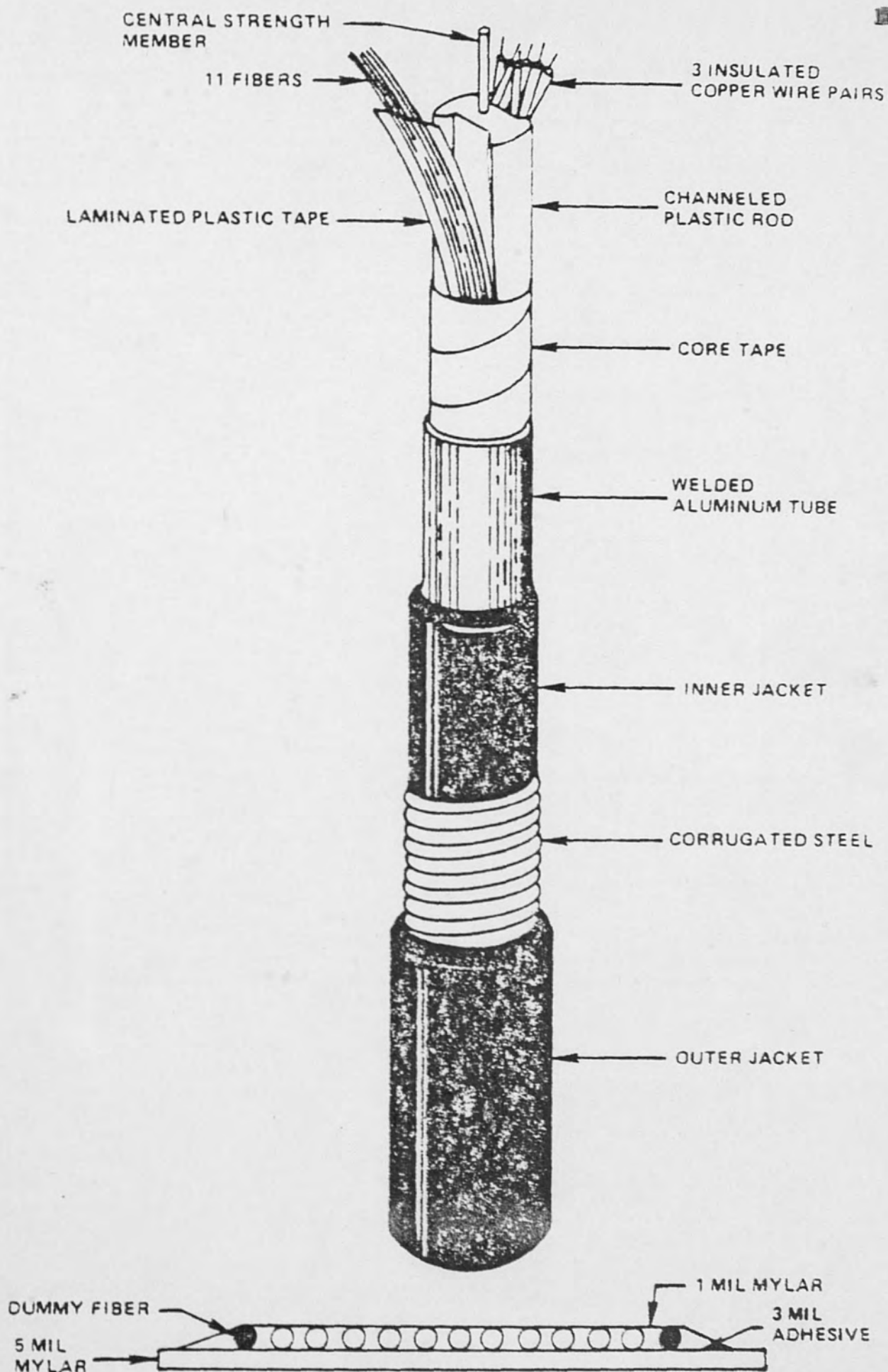
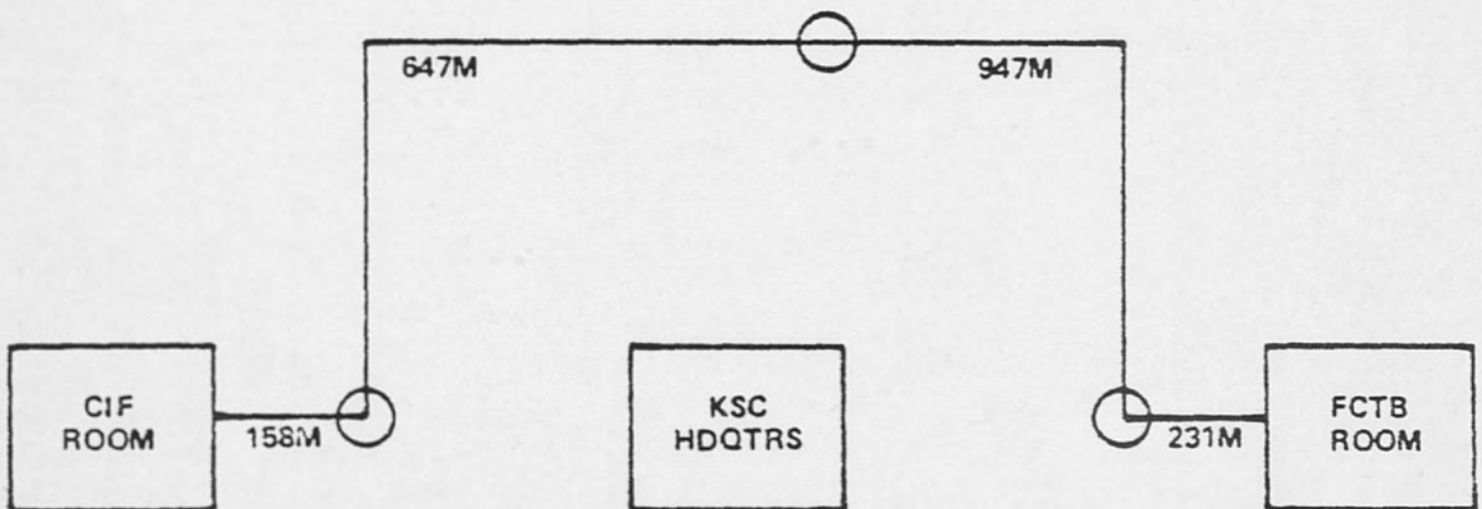


Figure 5. Fiber optic cable

sion System (CCTV) was used in the manholes to monitor a dynamometer which indicated cable tension. The designed redline limit of the cable was specified to be 900 pounds. The maximum tension experienced in the 3,114 foot pull from the FCTB to the Headquarters Building was approximately 360 pounds. The pull followed a path through seven manholes and included a 90° turn. After mechanically pulling this run, the cable was not damaged in any way and all eleven fibers were intact. The 2,200 foot run between the CIF and the Headquarters Building was pulled successfully also.

The cable was spliced in three places: in front of the FCTB; in front of the Headquarters Building; and outside the CIF (See Figure 6). Splices were made by actually heat fusing or welding the glass together. This was done by first cutting the fiber as clean and flat as possible. Cuts as flat as 0.5 um with an average of 3-4 um were made using a diamond blade. The ends were then placed in the fuser which used tungsten electrodes to produce the arc which actually welded the fiber together. These splices incurred a loss of less than 1 dB at each of the three splice points.

In the CIF and FCTB the cable was routed to a fiber optic distribution box. This box housed the loop splices made at each end and also allowed breaking out the fibers for light source launch purposes. Being able to splice at both ends of the cable made it possible to splice together a single fiber over 20 kilometers long. This splicing made it easy to simulate an O&C to OPF data length.



C.I.F. - CENTRAL INSTRUMENTATION FACILITY

F.C.T.B. - FLIGHT CREW TRAINING BUILDING

CABLE LENGTH: 1985 METERS

10-FIBER CABLE PERFORMANCE: 6.8db/km, 600MHz-km

● MANHOLE

Figure 6. Fiber optic test cable route

CHAPTER V

FIBER OPTIC CABLE TESTING

A great deal of consideration was given to the types of tests to be performed on the cable after installation. The most important factor was the actual ability of the fiber optic system to be a reliable data link between facilities. For this reason, the tests were designed to detect any changes in an installed cable as well as evaluate the capabilities of the system. Accordingly, six tests were chosen as follows:

1. Attenuation
2. Numerical Aperture
3. Dispersion
4. Spectral Response
5. Modal Distribution
6. Environmental

These tests, as well as terminal electronics testing, would give an effective means by which to judge the feasibility of using fiber optics at KSC. All tests were run and the data reduction performed by a Hewlett-Packard Computer/Controller and Network Analyzer System.

The attenuation test was performed to obtain a representative figure for expected attenuation in a fiber optic system up to 20 kilometers in length. To perform this test a HeNe laser (632.8 nm)

was used as a source. The source was launched onto the fiber and monitored by a silicon photocell detector connected to a power meter. A plot of the attenuation vs time was then made. The average attenuation for 10 fibers was 12.6 dB. The average attenuation after the pressure terminals were applied was 13.6 dB. The increase in attenuation per pressure terminal was 0.5 dB.

Numerical apertures of fibers were monitored to detect any changes in the cable possibly caused by environmental factors. A HeNe laser was again used as a source to launch a beam on the fiber. A detector was placed on a rotary stage which rotates $\pm 20^\circ$ from center in 0.2° increments. This allowed the HP monitoring system to monitor the power output at different angles and to compare this power output to previous data.

Dispersion testing was performed to help determine the data rate capability and therefore, the useful bandwidth of the fiber. An injection laser diode (820 nm) was used as a pulsed source. A change in pulse length was then determined by use of a digital processing oscilloscope (DPO) and pulse spreading read as nanoseconds per kilometer of fiber.

A spectral response test was performed to determine any change in the fibers. A broadband white light source was used in conjunction with a rapid scanning spectrometer plug-in for the DPO and the power output vs optical wavelength monitored. Periodic readings were made and results compared to stored data to identify any changes possibly due to environmental factors.

The modal distribution tests involved monitoring light patterns coming from the fibers. A charge-coupled detector array was used to look at these patterns and compare them to previous data.

The terminal and repeater equipment used in the tests consisted of Harris transmitters and receivers. Several configurations (See Figure 7) were employed in the testing. One configuration utilized an 8-kilometer system without repeaters. This system was operated from 50 MBPS to 150 MBPS. The 8-kilometer length was obtained by appropriately splicing the cable fibers to loop the data back and forth between the FCTB and the CIF (See Figure 7). One end of the loop was terminated at the transmitter, the other end at the receiver. A second configuration utilized a 16-kilometer system with two repeaters (See Figure 6) in the testing. This system was operated at 50 MBPS to 150 MBPS. Additional fibers in the test cable were spliced to provide the proper length (See Figure 7). The transmitter used in these tests utilizes a long lifetime injection laser diode, a high performance driver and feedback bias circuitry capable of operating up to 50 MBPS. The receiver has a linear operating range from 2 KHz to 500 MHz.

These tests demonstrated that 50 MBPS NRZ data can be transmitted over a 8-kilometer link with link margins of 10^{-12} dB and a BER of better than 10^{-11} . This configuration used no repeaters, but used a 30 MHz low-pass filter to limit the bandwidth in the receiver. Without the filter the system had a 3 dB link margin with a BER of better than 10^{-6} .

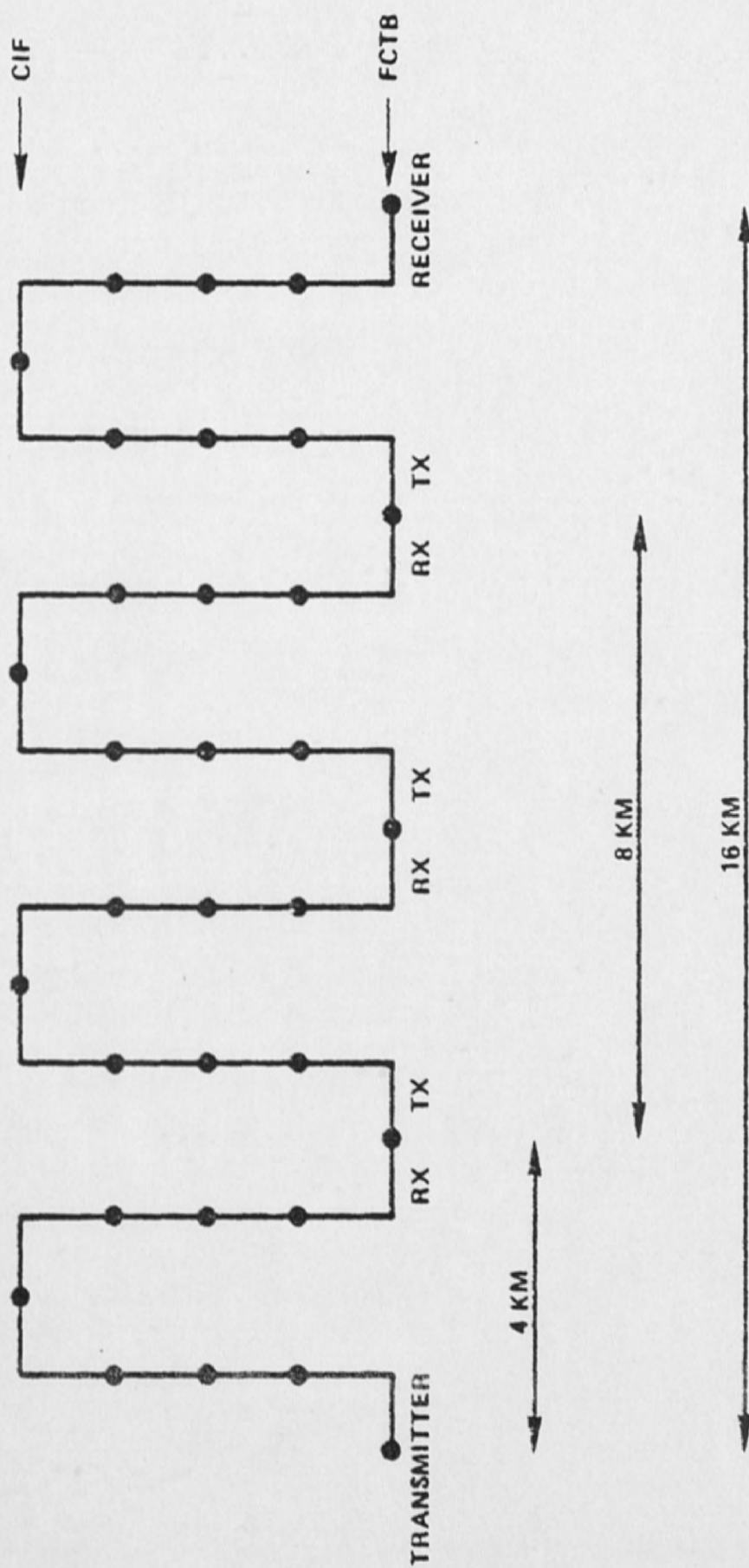


Figure 7. Link configuration diagram

Additional testing, using filters, provided the following results over the 8-kilometer link without repeaters.

<u>Bandwidth</u>	<u>BER</u>	<u>Link Margin</u>
100 MBPS	10^{-10}	5 dB
130 MBPS	10^{-8}	1 dB

Additional testing, using filters, provided the following results over the 16-kilometer link using two repeaters.

<u>Bandwidth</u>	<u>BER</u>
130 MBPS	10^{-9}

Additional testing, using optimized filters, provided the following results over a 4-kilometer link without repeaters.

<u>Bandwidth</u>	<u>BER</u>
322 MBPS	10^{-9}

CHAPTER VI

CONCLUSIONS

Fiber optic transmission systems are now a proven technology. This is especially true for the fiber optic systems investigated at KSC. As such, fiber optics has been found to have many inherent benefits. Fiber optic transmission systems ^{Price has decreased} ~~have been getting cheaper~~ each year (now \$473,000 for the KSC system) compared to the KU-Band transmission system (now \$560,000). The fiber optic system is capable of a very wide bandwidth (DC to 322 MHz), is immune to induced electrical interference and does not radiate EMI. Fiber optic transmission systems have low attenuation and are immune to adverse temperature and moisture conditions as well as voltage differential and grounding problems. Other advantages of fiber optic transmission systems include increased signal margin and immunity to weather conditions. In addition, fiber optics can serve as a general pupose data link, being usable for other potential Shuttle transmission requirements. KSC planning for future transmission systems indicate that fiber optics are to be used for transmission links inside the O&C building, between the O&C building and the vertical processing facility, and between the O&C building and the Satellite Tracking Station. No RF clearance is required when using fiber optics, thereby reducing frequency clearance scheduling problems. Since procurement lead-time is less for off-the-shelf fiber optic equipment, funding obligations are not

required as early as for the flight type items required for the KU-Band system. This time savings would allow competitive bidding contracts to be utilized for fiber optic equipment procurement, rather than having to go sole source procurement for KU-Band equipment. This type procurement further reduces the cost of the fiber optic transmission system. Finally, KSC would gain "operational" experience in a technology almost certain to be used extensively in the future. Therefore, it is concluded that the fiber optic transmission system should be installed for Spacelab high rate data checkout, not only for technical reasons, but for budgetary reasons also.

APPENDIX I

RF ATTENUATION

The RF signal path between the Spacelab installed in the Orbiter at the OPF and the RF receiving station in room 4227 of the O&C building is shown in Figure 8. The power loss/gain ratios shown graphically on the Link Power Diagram in Figure 3 were derived as follows:

- A. The output of the Orbiter transmitter is rated at 50 watts.

$$\begin{aligned}\text{dbm} &= 10 \log P_o/P_{in} \\ &= 10 \log 50,000 \text{ mw}/1 \text{ mw} \\ &= 10 \times 4.6999 \\ &= 47 \text{ dbm}\end{aligned}$$

- B. The Orbiter signal splitter will couple -25.8 db of power from the transmitter.
- C. The line loss from the Orbiter signal splitter to the OPF signal splitter is -2.0 db.
- D. The OPF signal splitter couples -10db to the transmission line.
- E. The waveguide switches, adapter and waveguide attenuation is estimated to be -12 db (4.7 db/100 feet for EW 132 waveguide).
- F. The four foot diameter transmission antenna is rated to provide a gain of +42.6 db.

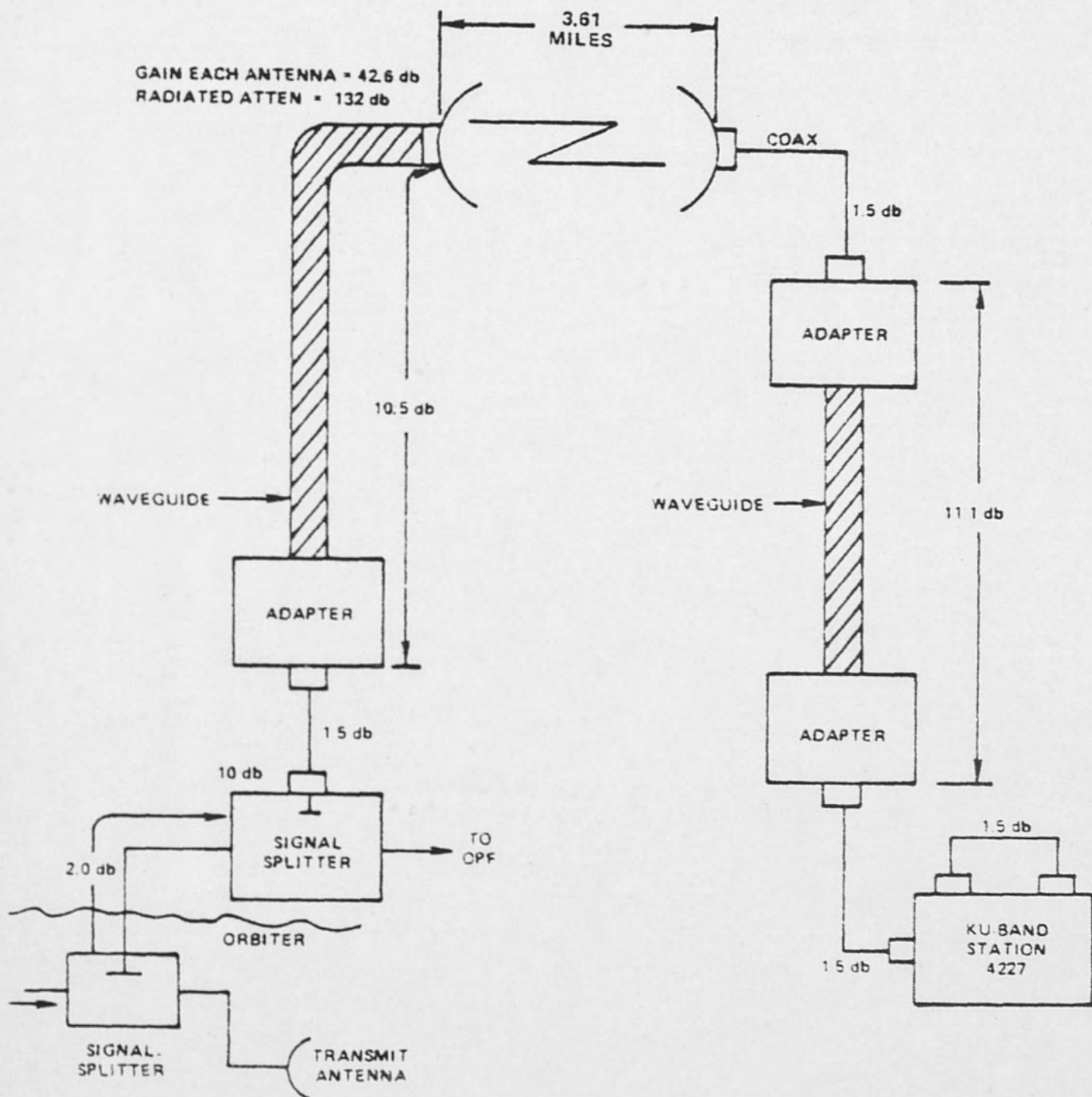


Figure 8. Ku-band rf signal path

- G. The anticipated radiated transmission loss (on a clear day) is -131.2 db.

$$\begin{aligned}
 \text{db} &= 36.58 + 20 (\log f(\text{MHz}) + \log D(\text{miles})) \\
 &= 36.58 + 20 (\log 15003.4 + \log 3.61) \\
 &= 36.58 + 20 (4.176 + 0.5575) \\
 &= 36.58 + 20 (4.7335) \\
 &= 36.58 + 94.670 \\
 &= 131.2 \text{ FREE SPACE ATTENUATION}
 \end{aligned}$$

$$\begin{aligned}
 \text{db} &= \text{FREESPACE ATTENUATION} + \text{ATMOSPHERIC ATTENUATION} \\
 &\quad + \text{pointing}
 \end{aligned}$$

$$\begin{aligned}
 \text{db} &= 131.2 + 1.1 \\
 &= 132.3 \text{ TOTAL} \\
 &= -132.3 \text{ TOTAL LOSS}
 \end{aligned}$$

- H. Another gain of +42.6 db is realized from the four foot receiving antenna.
- I. The waveguide adapters and wave guide attenuation is estimated to be 14 db (4.7 db/100 feet for EW 132 waveguide).
- J. The RF patch panel will add approximately 1.5 db attenuation to the signal.

Therefore, the anticipated signal strength at the O&C receiver (See Figure 3) is -65.5 dbm with +47 dbm as the output power of the transmitter.

APPENDIX II

RECEIVER INPUT REQUIREMENTS

The following parameters were utilized to determine the expected noise level at the receiver input and to determine the receiver signal input level:

- B - Noise bandwidth in Hz.
- BER - Bit Error Rate
- F - Noise figure (power ratio)
- k - 1.38×10^{-23} joules/°K. (Boltzmann's constant)
- L - Power loss ratio between receiver and antenna.
- N - Noise power in watts
- TA - Effective antenna temperature.
- Te - Effective receiver noise temperature in °K.
- TL - Temperature of losses between antenna and receiver (normally at 290°K).
- TR - Receiver noise temperature referred to its input.

The receiver noise temperature was calculated as follows:

$$TR = (F - 1) 290^{\circ}\text{K} \quad \text{TLM Handbook}$$

The noise figure is 12 db for the receiver. Therefore,

$$10 \log F = 12 \text{ db}$$

$$F = \log^{-1} 1.2$$

$$= 15.85$$

$$\begin{aligned}
 \text{So, } TR &= (F-1) 290^\circ\text{L} \\
 &= (15.85 - 1) 290^\circ\text{K} \\
 &= 4306^\circ\text{K}
 \end{aligned}$$

The effective receiver noise temperature was calculated as follows:

$$Te = TR + \frac{TA}{L} + TL \left(1 - \frac{1}{L}\right)$$

Assume $TA = TL = 290^\circ$

$$\begin{aligned}
 Te &= 4306 + \frac{290}{L} + 290 \left(1 - \frac{1}{L}\right) \\
 &= 4306 + \frac{290}{L} + 290 - \frac{290}{L} \\
 &= 4306 + 290 \\
 &= 4596^\circ\text{K}
 \end{aligned}$$

Formulas: "HANDBOOK OF TELEMETRY AND REMOTE CONTROL", Gruenberg.

The noise at the input to the receiver was calculated as follows:

$$\begin{aligned}
 N_w &= K Te B \\
 &= 1.38 \times 10^{-23} \times 4596B \\
 &= 6.34 \times 10^{-20} B \text{ Watts} \\
 &= 6.34 \times 10^{-17} B \text{ milliwatts} \\
 N_o &= 10 \log 6.34 \times 10^{-17} + 10 \log (B) \\
 &= 10 (-16.19) + 10 \log (B) \\
 &= -162 \text{ dbm} + 10 \log (B) \\
 &= -162 \text{ dbm} + (\text{Hz})
 \end{aligned}$$

The required signal level at the input to the receiver was calculated as follows:

A.	Bandwidth (B) of incoming sign	76.8 db
B.	N_0 dbm (Hz)	-162 dbm
C.	Bandwidth plus noise (A + B)	-85.2 dbm
D.	All required E_b/N_0 for BER of 15^6 (per vender)	10.6 db
E.	Add system losses (vendor)	5.0 db
F.	Add power per channel	1.0 db (80%)
G.	Subtact bit sync/Viterbi coding gain	<u>-4.5 db</u>
H.	Required signal at reciver (add C-G)	-73.1 dbm

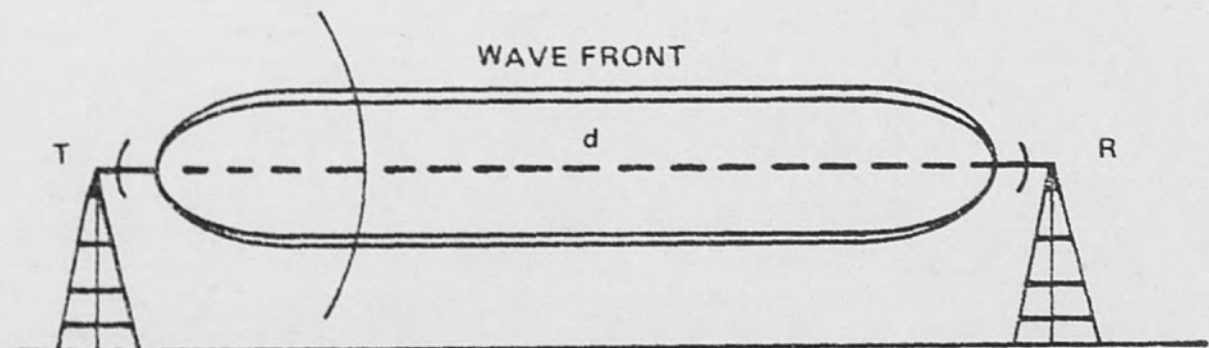
APPENDIX III

FADING

Fading is a condition which results in changes in the amplitude of the received wave at the receiving antenna. Fading of the signal in the link between the OPF and the O&C can be caused by any of the following effects:

1. Fresnel Zone. This zone is described as a cylindrical area whose center is the direct or shortest path from the transmitter to the receiver and which is spaced from the center sufficiently to increase the direct path length by one-half wavelength.

The radius of the zone at any point along the transmission path depends on the operating frequency and the spacing between the transmitting and receiving antennas.



FRESNEL ZONES SURROUNDING THE DIRECT BEAM

It is found from the following formula:

$$R = 13.15 \sqrt{\lambda \frac{D_1 \times D_2}{D_3}}$$

in which:

R = First Fresnel zone radius in feet at any point in the path

D_1 = Distance from transmitter to the point in miles

D_2 = Distance from the receiver to the point in miles

D_3 = Distance from transmitter to receiver in miles

λ = Wavelength in centimeters (2 centimeters for 15 GHz)

Using a distance from the OPF to the O&C Building of 3.61 miles, the maximum value of R occurring at the midpoint of the transmission path is 17.67 feet, which will clear all buildings and trees.

$$\begin{aligned} R &= 13.15 \sqrt{(2) \frac{1.805 \times 1.805}{3.61}} \\ &= 13.15 \sqrt{1.805} \\ &= 13.15 \times 1.344 \\ &= 17.67 \text{ feet} \end{aligned}$$

2. Reflection. The path from the OPF to the O&C is a line of sight path. Sufficient clearance exists above any interference (greater than 35 feet) to preclude reflections from ground, water, buildings and trees.

3. Refraction. Refraction is the bending of waves due to changes of the dielectric constant of the atmosphere, This bending could cause the waves to miss the intended receiving antenna. However, the path from the OPF to the O&C is relatively short (3.61 miles). Since the beam width at the O&C is expected to be approximately 265 feet, no refraction problems are anticipated.
4. Rain and Fog. Fog is not expected to be an area of concern at KSC, however rain attenuation affects the RF transmission path in the KU-Band frequency. The following increases in RF attenuation as obtained from the "Handbook of Telemetry and Remote Control," can take place over the 3.61 miles:
 - a. On a normal clear day, a total RF signal attenuation increase for 3.61 miles is equal to 0.09 db.NOTE: This value was added to the free space attenuation of 132.3 db.
 - b. During a moderate rain (6 mm/hr or 0.24 in/hr), an attenuation of 0.94 db is anticipated..
 - c. During a heavy rain (22 mm/hr or 0.87 in/hr), an attenuation of 6.26 db is anticipated.
 - d. During a cloud burst (42 mm/hr or 1.67 in/hr), an attenuation of 15.6 db is anticipated. This amount of attenuation would cause the signal level to be well below the requirements for the receiver.

APPENDIX IV

EQUIPMENT LOCATION

Option 1 locates the soft decision bit synchronizer and the Viterbi decoder combination in the O&C Building (See Figure 9). This location is advantageous in that the outputs of the Viterbi decoder (data and clock) are in phase and are driven hard. In the C&T Station, the output of the KU-Band demodulator is encoded data (from 4 MBPS to 100 MBPS) which is sent to a level detection fiber optic driver. A disadvantage of using a level detector is that it will be making the "one" or "zero" decision on the data. This configuration loses the soft decision capability of the bit synchronizer and presents a problem in designing an effective level detector to receive the output of the demodulator. The output of the demodulator can be down to 50 mv RMS with the signal 4 db below the signal-plus-noise level. This option is not practical for a low or varying receiver signal strength. Signal strengths will vary due to weather and location of the Orbiter (OPF or Pad).

Option 2 locates the equipment similar to Option 1 (See Figure 10), except the problem of making a hard decision at the C&T Station is addressed by using an analog fiber optic link to send the output signal of the demodulator to the soft decision bit synchronizer located in the O&C Building. The advantage of this option is that the signal is faithfully reproduced at the bit synchronizer, and a

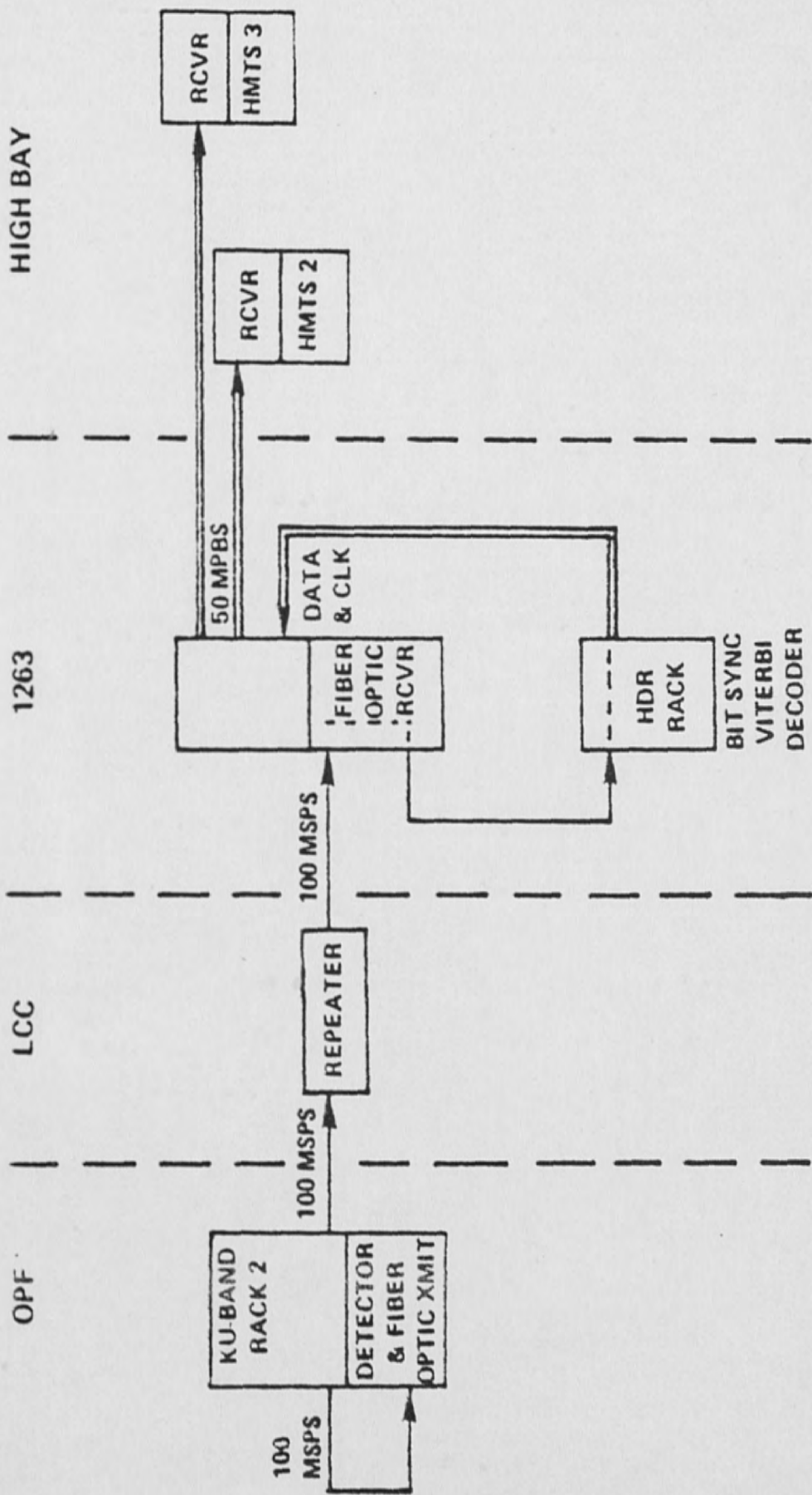


Figure 9. Fiber optics equipment location
option 1

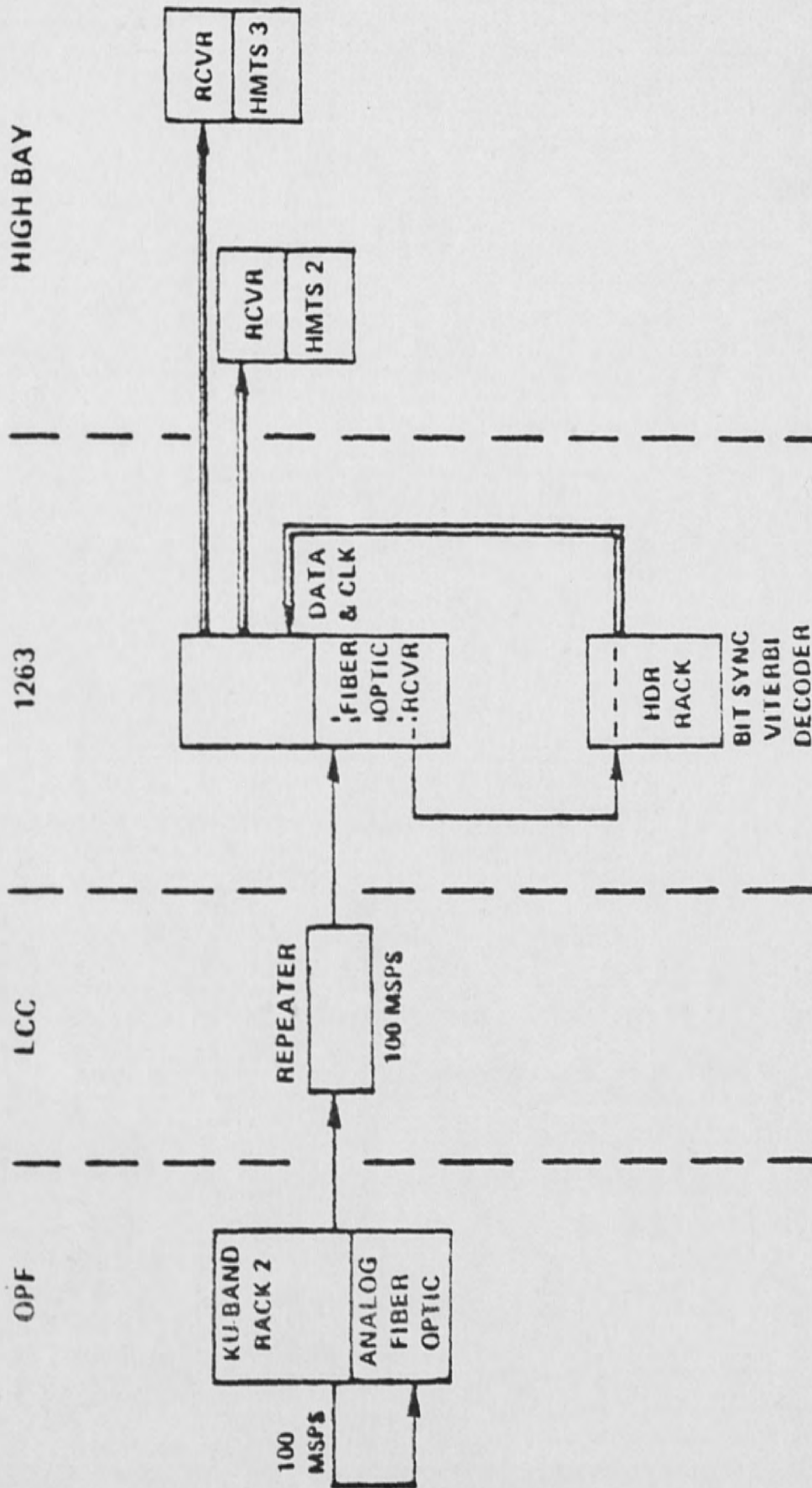


Figure 10. Fiber optics equipment location
option 2

system gain of 2 db will be achieved by the bit synchronizer. A disadvantage of this option is that most vendor technology is directed toward digital data transmission, even to the point of digitizing analog data for digital transmission. For this option to be viable, the analog link must have an overall minimum SNR of 38 db. Maintenance, setup and adjustment of the drivers, repeaters and receivers to achieve these requirements would be very time consuming. Furthermore, transmission of analog data accumulates noise and distortion products at each transmitter, repeater and receiver. Therefore, there is a finite limitation to analog transmission while maintaining a high SNR.

Option 3 utilizes the same placement of basic components as Options 1 and 2 except that a hard decision bit synchronizer is added at the OPF (See Figure 11) to supply a "clear" logic 1 or 0 to a digital fiber optic link. Adding a bit synchronizer overcomes the problem in Option 1 of detecting the signal level from the demodulator. This option has the same disadvantage as Option 1 in that the soft decision capability of the bit synchronizer is lost (approximately 2 db).

Option 4 places the soft decision bit synchronizer and the Viterbi decoder (high rate data rack) in the OPF (See Figure 12) next to the KU-Band receiver. The vendor has designed the two devices to operate together, therefore no interface problems should exist if they remain together. The decoded data and clock from the output of the Viterbi decoder are not only in phase, but both out-

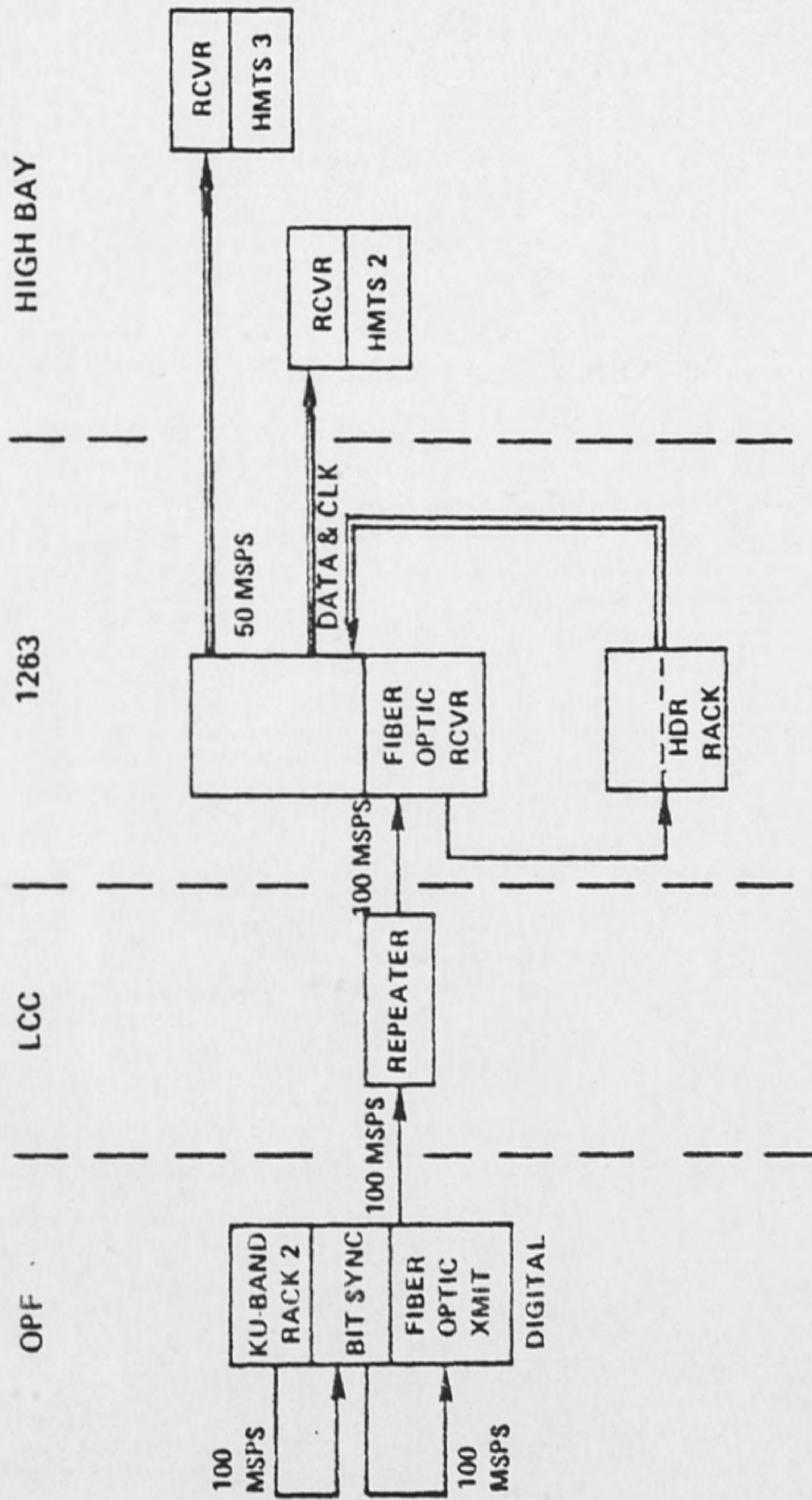


Figure 11. Fiber optics equipment location
option 3

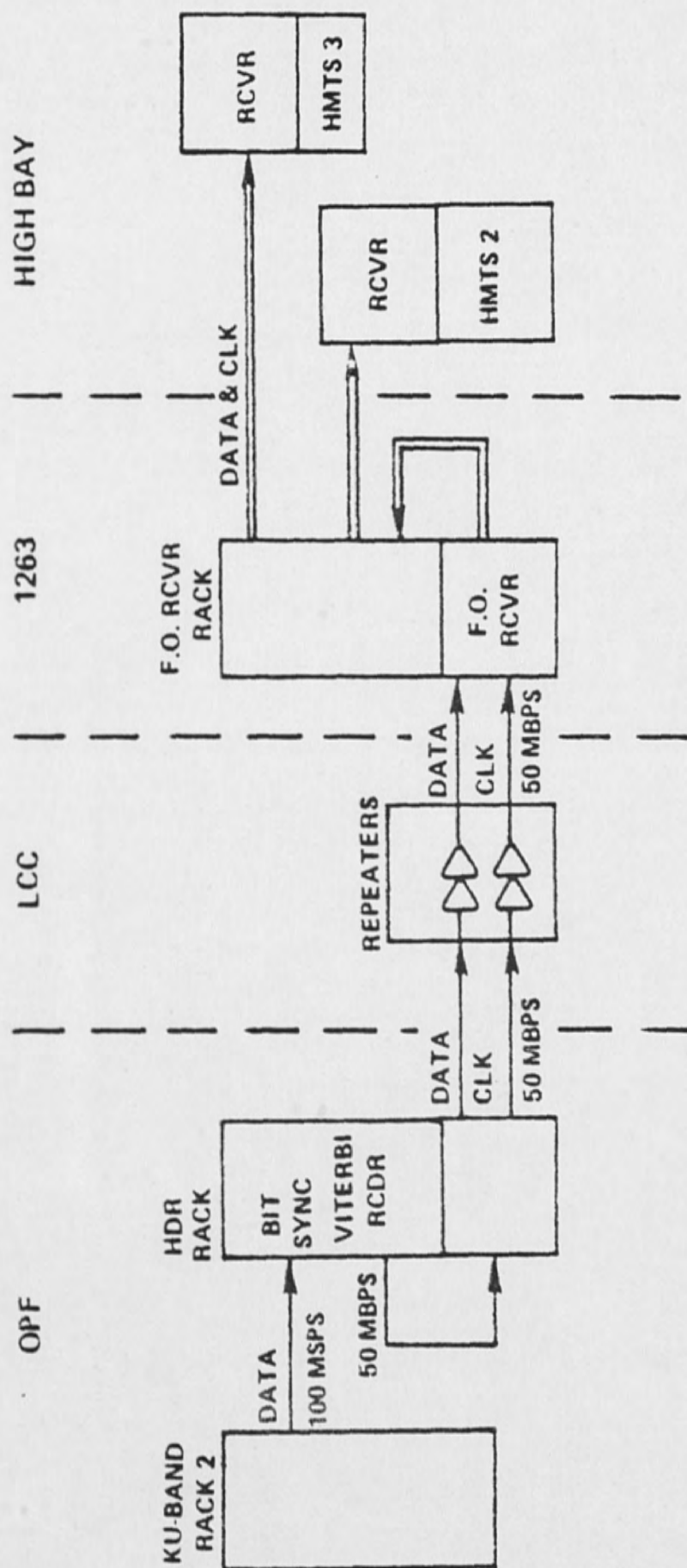


Figure 12. Fiber optics equipment location
option 4

puts from the Viterbi decoder are low distortion digitized signals and can be terminated in a fiber optic driver circuit. The disadvantage of this option is the difficulty in obtaining proper phasing. By the time the clock and data are received by the fiber optic driver circuit, transmitted through repeaters, and received at the O&C building, the phasing between the clock and data may be out of tolerance. Individual components, such as drivers, repeaters, and even the cable itself, can change characteristics due to temperature, age, and humidity. The problem of clock and phasing can be corrected at the output of the fiber optic receivers in the O&C Building with delay lines or a digital integrated delay circuit. In any case the data must be properly clocked.

Option 5 locates the equipment the same as Option 4; however, a "clock generator" is added in the O&C Building (See Figure 13). In the OPF the 100 MSPS data from the Ku-Band demodulator feeds directly into the High Rate Data Rack (bit synchronizer and Viterbi decoder) with the output being 50 MBPS data and an in-phase clock signal. The data and clock signals are "signal conditioned" and transmitted to the O&C Building by a single fiber optic line. In the O&C this signal drives a "clock generator" which provides an in-phase data and clock signal for distribution. This option supplies a low distortion interface at the C&T Station for the fiber optic transmission link and a proper phasing relationship between data and clock.

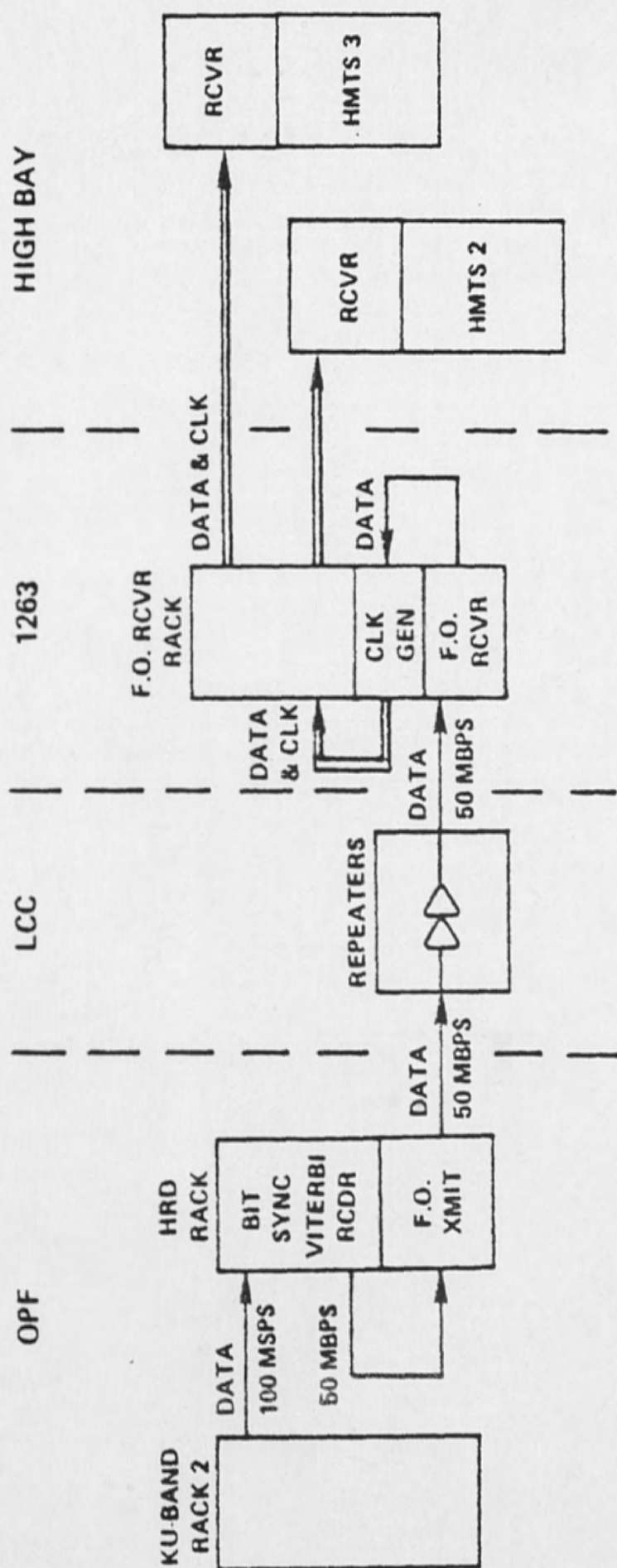


Figure 13. Fiber optics equipment location
option 5

GLOSSARY

ACCEPTANCE CONE - A parameter that defines acceptable light launching angles. Only light launched at angles within this cone will be waveguided.

✓ATTENUATION - A decrease in energy per unit area of a wave or beam of particles occurring as the distance from the source increases; caused by absorption or scattering.

CLADDING - The low refractive index material that jackets a fiber core and provides optical insulation and protection.

COMMUNICATIONS AND TRACKING STATION - A 40 x 60 foot room in the OPF containing Ground Support Equipment necessary to test the Orbiter Communications and Flight Control System.

CORE - The central region of a fiber. The refractive index of the core must be higher than that of the cladding.

DISPERSION, MATERIAL - Broadening of light impulses arising from wavelength-dependent differential delay of light in a waveguide material.

DISPERSION, MODAL - A fiber bandwidth-limiting factor caused by differences in the propagation characteristics of the various modes in a multimode fiber.

FIBER OPTICS - The art of active and passive guidance of optical radiation (rays and waveguide modes) along transparent fibers through predetermined paths.

GRADED INDEX FIBER - A fiber whose refractive index profile progressively decreases away from the center.

GROUND SUPPORT EQUIPMENT - Electrical, mechanical and fluid equipment necessary in the test and launch of manned and unmanned vehicles.

HIGH RATE DATA SYSTEM - One of the systems on the Spacelab used to multiplex 0-50 MBPS data from various sources and route these data to either the Orbiter or a ground station for evaluation.

MULTIMODE FIBER - A fiber that supports propagation of more than one mode of a given wavelength.

NUMERICAL APERTURE - A measure of a fiber's light acceptance.

OPERATIONS AND CHECKOUT BUILDING - A building utilized for test and checkout of horizontal payloads prior to installation into the Orbiter at the OPF.

ORBITER PROCESSING FACILITY - A building utilized for test and checkout of the Orbiter prior to installation of payloads to be carried into space orbit.

REFRACTIVE INDEX - The ratio of the velocity of light in a vacuum to the velocity of light in the specified medium.

SINGLE MODE FIBER - A fiber waveguide that supports only one mode of propagation.

SPACELAB - A payload built in a coordinated effort by a group of European countries to be flown repeatedly in the Orbiter. The payload is sufficiently large to be utilized by scientists during space orbit.

STEP INDEX FIBER - A fiber that gives an abrupt change in the refractive index at the core cladding interface.

TRANSMIT DATA RELAY SATELLITE SYSTEM - A communications satellite system consisting of three satellites to be launched in the Orbiter on separate missions and used for communications by the Orbiter and the various communications and tracking facilities such as the Goddard Communications and Tracking Facility at the Kennedy Space Center and the Mission Control Center at Houston, Texas, as well as various commercial communications centers.

VITERBI DECODER - A decoder utilizing a decoding scheme by A. J. Viterbi which represents a methodical approach for choosing the most likely input data stream from a noise-corrupted transmitted (and received) stream. The approach accomplishes this choosing by measuring the discrepancies between successive input words and all possible input words emanating from, and merging at each state of the expanded state diagram and maintaining a record of accumulated errors as well as the responsible data sequences.

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